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AN APPROACH TO AUTOMATED WAREHOUSES ANALYSIS AND DESIGN

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ANALYSIS AND DESIGN

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SUMMARY

For the last few years, management has been paying increased attention to the function of warehousing, as it realized that the cost associated with this function constituted a substantial part of total production cost.

One of the possible improvements for the operation related to warehousing is the application of computers and automated materials handling equipment to warehousing activities such as storing, dispatching, order picking and record keeping.

In order to obtain information on the planning and operating problems and procedures of existing automated warehouses, a questionnaire was prepared and sent to the operators of over 40 automated warehouses in the United States. Using this information as a basis, several charts were designed to help analysts in the selection of the appropriate level of mechanization, and type of equipment, for each warehouse activity. A general procedure for developing an automated warehouse is also suggested in this study.

The results of this study indicate that, in addition to expected dollar savings, other benefits can be gained from an automated warehouse which may be equally or even more important to the success of the enterprise. Most important among these are:

1. Better customer service,
2. Better inventory control,
3. Less damage and pilferage, and
4. Public relations value.

The feasibility of automating or mechanizing a warehouse activity appears to depend on a great number of factors. Numerous factors have been identified in this study, but there are three that seem essential: presence of a large volume, relatively steady volume, and minimum variety in the sizes and shapes of the units handled.

Finally, from the research conducted during this study it appears that the practice of applying mechanized and automated equipment in the warehousing function of an enterprise is well justified as a means of improving the economics of operation of this important function.

CHAPTER I

INTRODUCTION

Warehouses have existed since primitive man found he had more than he needed to eat and decided to store the surplus. When man became a farmer he was forced to develop more formal warehouses to store his grain. Today, warehouses constitute an important part of the marketing strategy of the firm in improving service and lowering cost.

It is the purpose of this study to provide management with meaningful information that will be helpful in reaching a sound decision when considering the design of a new warehouse, or the improvement of a present installation.

The storage of raw materials needed in production operations and the subsequent storage of finished goods is unavoidable in any society. This supply of commodities is called inventory. The need for storage facilities arise from:

1. Delays incident to manufacturing schedules;
2. Delays in marketing, i.e., locating buyers, negotiating prices, quantity, delivery dates, etc.; and
3. The irregular demand for some goods (seasonal goods).

Storage, however, is not the only activity performed in warehouses. It is just one of a group of activities under the general heading of warehousing. These activities have been classified as follows (1).

1. Receiving is concerned with those activities involved in

accepting materials delivered to the warehouse. The primary objective of this activity is the fast and accurate processing of receipts. It is usually not automated, but accomplished in traditional manner with carts, trucks, conveyors, etc., to aid in unloading of carriers.

2. Identification and Sorting is concerned with determining what is received, and deciding where it should be stored.

3. Dispatching to storage is defined as the movement of goods to their desired or required locations.

4. Storage is the activity whose function is to hold, protect and preserve merchandise until it is wanted to use.

5. Order picking is considered the most important activity in the warehouse. It consists of withdrawing items from storage as called for.

6. Order accumulation consists of assembling or accumulating the items making up a specific order.

7. Packing consists of providing protection for the items.

8. Loading consists of loading the packed items into the carriers.

9. Shipping is the last step between the maker and the user. It consists of documenting the loading operation and in the transportation itself.

10. Record keeping is the overall function of producing and maintaining the necessary records and paperwork to assure an efficient warehouse operation.

Approximately one-third to one-half of the total assets of a typical manufacturing company in the United States are invested in inventories. Moreover, approximately 18 cents of every sales dollar is spent in the storage and physical movement of the product. There are today two million people employed by some 200,000 large warehouses throughout the United States, with an annual operating cost of over $20 billion (2). It is not surprising, therefore, that top management is beginning to pay attention to the warehousing function.

During the last two decades, a great deal of progress has been made in the fields of scientific inventory management and materials handling equipment. For example, operations research techniques, such as linear programming, simulation and dynamic programming have been applied to the problem of inventory (3) (4). In the field of materials handling, new equipment includes driverless tractor trains, driverless fork lift trucks, air flotation trucks, automatic conveyor systems, stacker cranes, and automated storage systems.

The advent of the computer, and its increased application to many phases of industry, has encouraged the use of more sophisticated and complex techniques to give far better control of goods in the warehouse, because of the close relationships between the movement of goods and the corresponding paperwork. The integration of electronic data processing equipment with the handling operations has started a new trend in warehousing: the automated warehouse.

Definitions

It may be helpful at this time to define the most important terms related to this study.

Warehousing can be defined as "a function which determines what and how much goods to store; provides the proper space for their safekeeping; controls the total storage activity; and provides a system to economically coordinate the necessary activities, facilities and manpower." (1)

The three basic types of warehouses are defined in Figure 1.

Type of warehouse	Characteristics	Equipment Needs
Manufacturing	Handle few kinds of items which enter and leave storage in relatively large lots.	Equipment for storage of bulk items.
Distribution	Maintain a large inventory. Items enter in large lots but leave in great number of small shipments.	Equipment to identify, sort, store and recall.
Transfer or Terminal	Items enter from many sources, are consolidated by destinations and dispatched as quickly as possible.	Equipment to identify, sort and recall.

Figure 1. Types of Warehouses.

Physical Distribution involves the coordination of those activities and functions necessary to place finished goods into the hands of the consumer. It usually includes such functions as:

1. Packaging,
2. Finished goods warehousing,
3. Related materials handling,
4. Order processing,
5. Traffic and transportation,
6. Customer service, and
7. Related communications and record-keeping activities.

Automation, for the purposes of this study, means the "application and coordination of control equipment to operate the mechanical equipment -- and part or all of the system served by it -- with little or no detailed attention." (24)

In most cases, reaching a state of "true automation" involves an evolutionary process which might be termed "the progressive steps to automation." (29) In each of these steps, a higher degree or level of mechanization is applied.

Mechanization is the "application of powered mechanical equipment in warehouse activities to augment the effectiveness of the labor force." (24)

In this study, both the mechanization and automation of warehouse operations will be analyzed.

As defined by Dallimonti (2), "an automatic warehouse integrates into a system the necessary information flow, required for operating business decisions in a closed loop, with all the physical handling and storage of the product." The three major elements which comprise this system are:

1. Management inventory policy,
2. Accounting and data handling procedures, and
3. Physical materials handling and storage operations.

However, most of the automated warehouses in this country today do not conform to this definition. The existing warehouses vary in the degree of mechanization and in the number of activities which are mechanized. Usually, one of the first steps is to automate the data handling and accounting functions, followed by the inventory control function. With respect to physical handling of goods, attempts have been made to automate the identification, dispatching, storing, picking and accumulation and record keeping.

As previously stated, management is turning its attention to the warehousing function as a potential area for cost reduction. As a result, several progressive companies have built mechanized, or automated, warehouses in the last ten years. Many of these installations have been successful, but others have not given the desired result, and therefore, have been closed and the equipment sold at a loss (5). The failure of these warehouses was due, in part, to application of automated warehouses to situations in which they were not justified.

The motivation for this study is the belief that:

1. Mechanization and automation of the warehousing function is desirable in many situations.
2. There exists an optimum level of mechanization for each particular warehouse situation.
3. Justification of an automated warehouse installation should be based on an economic analysis of the total distribution system.

Objectives

The primary objective of this study is to identify, and establish a method of evaluating, the factors influencing the feasibility of automating the warehousing function of an enterprise.

A further objective is to suggest an approach or procedure for developing an automated warehouse and for determining the optimum level of mechanization for each activity performed within the warehousing function.

Scope and Limitations

As implied by the first objective above, this study is limited to the identification and quantification of the factors for evaluating automation feasibility, based on the operational experience of those firms presently owning and operating automated warehouse. No personal observations of operational practices were conducted, due to the remote location of the present installations.

This study is not limited to a particular type of warehouse. That is, existing installations of both storage and distribution warehouses were investigated.

Although the importance of the social impact of automation is recognized, no attempt was made in this study to evaluate these problems with respect to the automatic warehouse since much has been written on this subject (6) (7), and it actually falls outside the scope of this study. Consideration will be given primarily to tangible economic factors with appropriate attention to relevant intangible factors.

CHAPTER II

LITERATURE SURVEY

Automation is not a recent development. It is the result of centuries of natural evolution with "expanding economy and changing consumer demands on industry, commerce and jobs playing equally important roles in its development." (8)

The introduction of no other word in our language has created so much stir as "automation". It has caused apprehension in the labor force, confused the public and brought new problems to industrial management. The word was first coined by Del S. Harder in 1946 (18) meaning at that time the linking of machine tools with automatic transfer and handling equipment. Today, its meaning goes beyond that definition, expanding and changing with each new application. Roger Bolz (9) defines automation as "the technology of manufacturing, processing, or performing services as automatically and continually as business economics demand."

Only since World War II have automation concepts been widely applied in American industry. At about the same time, management began to realize that warehousing was a basic industrial task deserving systematic analysis and refinements, as the costs associated with this function were a very substantial part of total production costs. It was only natural, then, that management considered automation as one of the possibilities for improvement of the operations involved in warehousing: storing, dispatching, order picking, etc.

The first mechanized installations appeared in this country in the early fifties. From 1956 to 1960, more than 50 mechanized warehouses were built (5), and again from 1960 to 1964 a similar number began operation (10). These installations varied with respect to the degree or level of mechanization employed, with that at the Kitchens of Sara Lee, Deerfield, Illinois being the first one that could be really called "automated" (11).

Some of these installations were so successful that the companies involved ordered new automatic facilities (12). However, other installations did not do too well. In the case of the Brunswig Drug Company at Los Angeles, the failure on the part of management to take into consideration the future sales trend and market area, caused the company to abandon its newly-built automatic warehouse in favor of a number of warehouses closer to their customers. The warehouse was closed and the equipment sold at a loss (5). This is a good example of what can happen when management rushes into the installation of sophisticated equipment without a careful analysis and economic justification of the investment, based on a study of the whole distribution function from a systems viewpoint and taking into consideration all relevant factors.

Since the beginning of the present decade, the emphasis has been more on the "feasibility" aspect than the "glamour" aspect of automation in warehousing. The challenge today is to design a system where cost will be in proper proportion to its advantages.

One of the first attempts to identify the factors involved in evaluating the feasibility of automated warehouses was an article that appeared in a leading magazine in the field of materials handling in 1963, where a list of factors was given, but no effort was made to quantify them (13).

This list of factors was presented, somewhat expanded, by R. P. Lane in a report presented to the School of Industrial Engineering of Georgia Institute of Technology in 1964, where he summarized the state-of-the-art of automated warehousing at that time (14). His work was primarily based on a publication of the Industrial Education Institute published the same year (15).

In 1963, a doctoral dissertation dealing with developments in the warehousing field was published (16). This dissertation documents the historical development of warehouses, the services they perform, and discusses the changes that have improved the warehousing function of late. One of the changes discussed is the trend towards automatic warehousing. The author states, without documentation, that "the criteria necessary to automate are steady volume, standardized packaging and stable market which will permit amortization of the system in four or five years." (17)

From 1963 to the present, many articles have been written in trade and technical magazines, but they deal mostly with descriptions of existing installations and available hardware, rather than the concept and economics of mechanized and automated warehousing. The means of implementing this concept exists today, and the motivation for doing so is increasing. All that is needed are sound criteria to guide warehouse designers through a feasibility study. This study is intended to provide planners and designers with the criteria necessary to help them decide when automation is justified, and how much.

Two important works have been published in the last ten years on the general field of automation. They will be referred to briefly due to their relationship to the general purpose of this study.

The first work is that of Bright (18), in which he develops a set of Levels of Mechanization. This set appears in chart form in Figure 2. Lossiyevskii and Pliskin (19) have defined two measures of automation: level and extent. By extent is meant the degree to which a series of activities has been mechanized. The levels are given as:

1. Manual performance of the operation.
2. Manual performance of an operation using manual operated auxiliaries.
3. Manual performance of an operation using power operated auxiliaries.
4. Local manual control of a power-operated device.
5. Manual remote control of a power-operated device.
6. Automation repetition of a fixed cycle for the performance of a single operation.
7. Automatic check of a process with the help of indicating and print-out devices requiring manual control of the process.
8. Signaling, automatic protection, blocking.
9. Automatic start and stop of the equipment in a working process determined by the presence of the product.
10. Automatic repetition of a fixed cycle, for the sequential performance of a series of operations.
11. Automatic registration and counting of the output of a technical device.
12. Automatic control of the parameters of a process, of the working conditions of a machine, with variation of these parameters, either from previously given values, or according to a program.

POWER SOURCE	Level Number	LEVEL OF MECHANIZATION
MECHANICAL	17	Anticipates action required and adjusts itself to provide it.
	16	Correct performance while operating.
	15	Corrects performance after operating.
	14	Identifies and selects appropriate set of actions.
	13	Segregates or rejects according to measurement.
	12	Changes speed, direction according to measurement signal.
	11	Records performance.
	10	Signals preselected values of measurement.
	9	Measures characteristic of work.
	8	Actuated by introduction of work piece or material.
	7	Power tool system, remote controlled.
	6	Power tool, program controlled.
	5	Power tool, fixed cycle.
	4	Power tool, hand control.
	3	Powered hand tool.
MANUAL	2	Hand tool.
	1	Hand.

Figure 2. Seventeen Levels of Mechanization.

(Adapted from Bright, "Automation and Management.")

13. Multipoint check on the parameters of a process, with periodical coupling to data transmitters.
14. Automatic control of the parameters of a process with automatic correction of the regulation of data transmitters by other regulations with multi-impulse operation, multi-point regulation.
15. Automatic check with continuous analysis of the composition and quality of complex products.
16. Automatic check of the compounded parameters of a process with the help of calculation solution techniques.
17. Automatic centralization of the registration of the progress of a technical process with the help of techniques used on computers.
18. Automatic control of the work of the subject, with automatic correctors for machines carrying out the production process, with automatic search for the optimum working conditions for the subject.
19. Automatic start and stop of a process according to a given program.
20. Automatic self-adjusting control of a process, keeping the process in step with changes in the optimum working conditions as related to changes in the internal and external influences felt during the run of the process.

Actually, both sets of levels of mechanization are very similar in many respects. The main difference is that, while those of Lossiyevskii and Pliskin are more sophisticated, the levels given by Bright are better defined and more applicable to existing situations.

Since part of this study is concerned with the economic analysis of the warehousing function, a survey of the engineering economy literature was conducted to ascertain which methods are most commonly used in industry for choosing among alternatives. The methods investigated were:

1. Pay-off period method.
2. Rate of return method.
3. Rate of return on extra investment method.
4. Equivalent annual cost method.
5. MAPI method.
6. Discounted cash flow method.
7. Profitability Index method.

The following nomenclature will be used in the formulae that describe each method:

CI = capital investment,

CRF = capital recovery factor,

EAC = equivalent annual cost,

EXP = annual expenses,

POP = pay-off period,

ROI = return on investment,

SV = salvage value,

I = annual income,

i = rate of return, per cent, and

n = service life.

1. Pay-off period method. This is the simplest and most frequently used method. The capital investment on a new system, divided into the

expected annual savings, will give the pay-off period in years.

$$POP = \frac{CI}{(I - EXP)} \quad .$$

2. Rate of return method. In this method, a rate of return, i, is calculated (using compound interest) and then it is decided whether it is sufficient to justify the investment.

$$\frac{CI}{ROI} = \frac{(1 + i)^n - 1}{i(1 + i)^n} \quad ,$$

where, for straight line depreciation,

$$ROI = (I - EXP) - \text{Income Taxes} + \frac{CI\text{-}SV}{n} \quad .$$

3. Rate of return on extra investment method. When one alternative requires a larger investment than the other, but involves lower operating costs, this method can be used to determine whether the extra investment in the most efficient alternative is worthwhile (20). The interest rate which will make the annual cost of both alternatives equal to each other is sought.

$$(CI_1\text{-}SV_1)CRF_1 + EXP_1 + SV_1(i) = (CI_2\text{-}SV_2)CRE_2 + EXP_2 + SV_2(i) \quad .$$

The equation is solved by trial-and-error. If the rate of return, i, found is acceptable to management, the alternative with greater capital investment is chosen.

4. Equivalent annual cost. The alternative with the minimum equivalent annual cost is selected.

$$EAC = (I\text{-}EXP) + CI \frac{i(1+i)^n}{(1+i)^n-1}$$

5. MAPI method. This method was developed by Terborgh for the Machinery and Allied Products Institute (21) (22). The procedure is essentially a conventional comparison of the next year's costs, with a time-valued adjustment to account for depreciation and anticipated decline in operating advantage during the present equipment life. It is an excellent method to use when considering replacement of an existing installation with new equipment, such as in the case of automating an existing warehouse.

The method has its limitations, however, in that the charts and formulae developed are based on certain assumptions. It is recommended that persons interested in this method study the two references given.

6. Discounted cash flow method. This method, existing in a number of variants (present value, final worth, etc.), is based on the concept of the time value of money. The profitability of an investment is dependent upon the cash flow: the amount and timing of the cash income and cash cost produced by the investment.

7. Profitability Index method. Reul (23) developed a fast and easy method for determining new equipment pay-off which is another variant of the discounted cash-flow method. It is called the "Profitability Index" (PI) Method. This method evaluates an investment by comparing the value of future income from the project with expenditures needed to

finance it. PI is that rate of interest which, when applied to the proposed investment, will yield annuities exactly equal to the anticipated yearly savings after income tax. Basically, the procedure is as follows:

1. Calculate present value of future investment and income at several trial rates of return.
2. Derive the ratio, for each trial, of the discounted total annual net profit.
3. Plot these ratios against the selected trial rates of return. The rate of return corresponding to a ratio of one will be the PI.

The PI will be the rate of return that will be secured by the proposed investment over the useful life of the installation.

As with the MAPI method, this procedure has its limitations and should be used with judgment. However, its simplicity makes it an excellent tool for analyzing alternative investments.

Conclusions

Of the seven methods of economic analysis discussed in this chapter, two can be singled out as being fast, easy and reliable methods for practicing engineers to use. These are the MAPI method and the Rate of Return method.

The use of the Rate of Return method as a tool for determining the profitability of a proposed investment is demonstrated in an example in Chapter VI.

CHAPTER III

METHOD OF PROCEDURE

The method of procedure employed in the present study consisted of the following major steps:

1. Collection of pertinent information on the planning and operating problems and procedures of existing mechanized and automated warehouses from:
    a. a questionnaire sent to companies operating mechanized and automated warehouses.
    b. publications in the fields of automation, materials handling and warehousing.
2. Analysis and evaluation of all data gathered.
3. Identification of the factors affecting the automatic-versus-manual decision.
4. Determination of a method of evaluating the significant factors.
5. Development of a procedural guide for designing an automated, or mechanized, warehouse operation.

Companies Surveyed

In selecting the companies for the survey conducted, three criteria were considered important. First, most of the major industries should be represented in the survey. That is, an effort was made to contact the greatest possible number of companies from different sectors of the economy. Second, it was deemed important to include companies in all size ranges. The smallest company contacted had 500 employees and the largest, 400,000 employees. Finally, it was considered essential to obtain information from companies operating "automated" warehouses with a wide range of levels of mechanization: from a single automatic conveyor or crane to a computer-controlled warehouse.

With these objectives in mind, a questionnaire was designed and sent to the operators of over 40 "automated" warehouses in the United States. Assistance in designing the questionnaire was obtained from half a dozen nationally recognized authorities on automated warehouses. A copy of the questionnaire and results of the survey appears in the Appendix.

CHAPTER IV

AUTOMATION AND THE WAREHOUSING FUNCTION

Mechanization and automation of warehouse operations have been difficult to justify in many situations where they have been indeed warranted. The reason for this is perhaps that management and materials handling men have been looking at the problem from too narrow a viewpoint. Warehousing is just a part of a bigger operation -- the distribution system -- and in many cases it is not planned and designed as such. However, the justification of an automation program for a warehouse operation may come from factors and reasons outside of the warehouse itself.

In this chapter, some of these reasons will be discussed. Also, a review of the basic concepts and types of equipment and control techniques that make an automated warehouse possible today will be presented.

Reasons for Automating

The advantages gained by automating a given warehouse activity will not only be the savings associated with the replacement of labor with mechanical equipment. The warehouse must be considered from the viewpoint of the top management of the business. In other words, all improvements proposed for the warehousing function should be considered in the light of how they will affect the business as a whole. Therefore, when considering automation for improving the warehousing function, the following factors should be taken into consideration:*

1. The High Cost of Distribution

Distribution costs in many industries represent a very high

*Adapted from References 1 and 15.

percentage of the sales dollar. For example, among consumer-goods that receive nationwide distribution, such as food and clothing, the warehousing and transportation cost can be as high as 10-30 per cent of the selling price of the product.

A recent survey conducted by Distribution Age shows that in six major industry groups the distribution costs (transportation, warehousing, materials handling, and shipping room expenses) were as follows:

Industry Group	Physical Distribution Cost as Percentage of Selling Price
Machinery	9.8
Wood products and furniture	16.1
Paper and paper products	16.7
Chemicals, petroleum	23.1
Primary and fabric, metals	26.4
Food and food products	29.6

Another study conducted by a management consulting firm revealed that the total cost added to a product by the distribution function was greater than that of any other function. For a typical consumer product, the cost added by each function is as follows: (25)

Function	Total Cost Added	
	Actual	Per Cent
Material	$ .23	11.5
Manufacture	.14	7.0
Selling	.81	40.5
Distribution	.82	41.0

In many businesses, management has invested countless man-hours and dollars in improving the manufacturing or production facilities. Automatic machines have been introduced that have lowered the labor content of production operations and have increased worker productivity, thus reducing production costs. As the distribution costs have not been reduced accordingly, they are becoming an increasingly higher proportion of total costs.

2. Demand for Better Customer Service

Customers are demanding faster service coupled with greater accuracy. An automated warehouse, by streamlining order handling and processing, and reducing errors in filling orders, is essential to good customer service.

3. Changing Patterns of Distribution

The last few decades have seen a change in distribution methods brought about by social, economic and technical pressures. These changes include:

a. A trend toward larger but fewer retail stores. The supermarket versus a dozen grocery stores is a vivid example.

b. Hand-to-mouth buying. Businesses at all levels -- manufacturer, distributor, retailer -- are changing their inventory policies in an effort to free capital for other purposes. Therefore, they are ordering more frequent and smaller shipments, depending on the vendor to carry inventory for them.

c. New products have increased in number. Consumers demand for product variation has caused product sizes, styles, colors and features to multiply. While the manufacturing problems associated with this can be reduced to changing a machine set-up, or changing the color of a dye, the warehousing problems are tremendous. More stock-keeping units must be stored and the order picking becomes more complicated.

d. Centralization of distribution. Although this subject is quite controversial -- that is, some claim great benefits for decentralization -- the trend seems to be toward centralization. Some advantages given are:

better communication,
elimination of duplicate inventory,
better customer service,
lower transportation cost and time,
better inventory control,
reduction in total floor space and costs,
automation more easily justified, and
less stock-outs.

4. Competitive Pressures

The changes and trends mentioned above are creating a necessity for warehousemen to provide faster and better customer service in order to retain their customers. If one supplier, by automating the warehousing function, can provide better service, his competitors must match this service or be exposed to the loss of business.

5. The Impact of Data Processing

Modern data processing equipment and techniques are partly responsible for the current interest in automated warehousing. In the completely automated warehouse, EDP integrates the material handling operations with the paperwork to obtain better management control of the whole operation. The results gained in many businesses from the automation of their paperwork have served as an incentive to apply the same principles to other segments of the business.

6. Benefits in the Warehouse Operation

The factors discussed above apply to the business as a whole. Some reasons for automating the warehousing function come from benefits within the warehouse itself, such as:

a. savings in direct labor costs,

b. reduced space requirements,

c. less damage and pilferage,

d. lower utility costs, and

e. greater capacity to handle overloads.

Basic Control Functions

When mechanizing or automating a warehouse, the operations performed in the warehouse activity areas can be implemented through a few common control functions. These basic control functions are identify, dispatch/accumulate, store and recall. Figure 3 shows the relationship between these basic functions and the activity areas.

The four basic control functions are:*

1. Identify

This function can be accomplished either manually or automatically. In the former, the operator visually recognizes different items and either put this information into a control memory system with push-buttons, or physically tags the item or its container. Automatic identification can be accomplished by using sensors which either detect and identify materials by direct contact (electromechanical limit switches, weighing devices, X-ray devices, electrical contacts) or without even

*Adapted from References 15, 24, and 26.

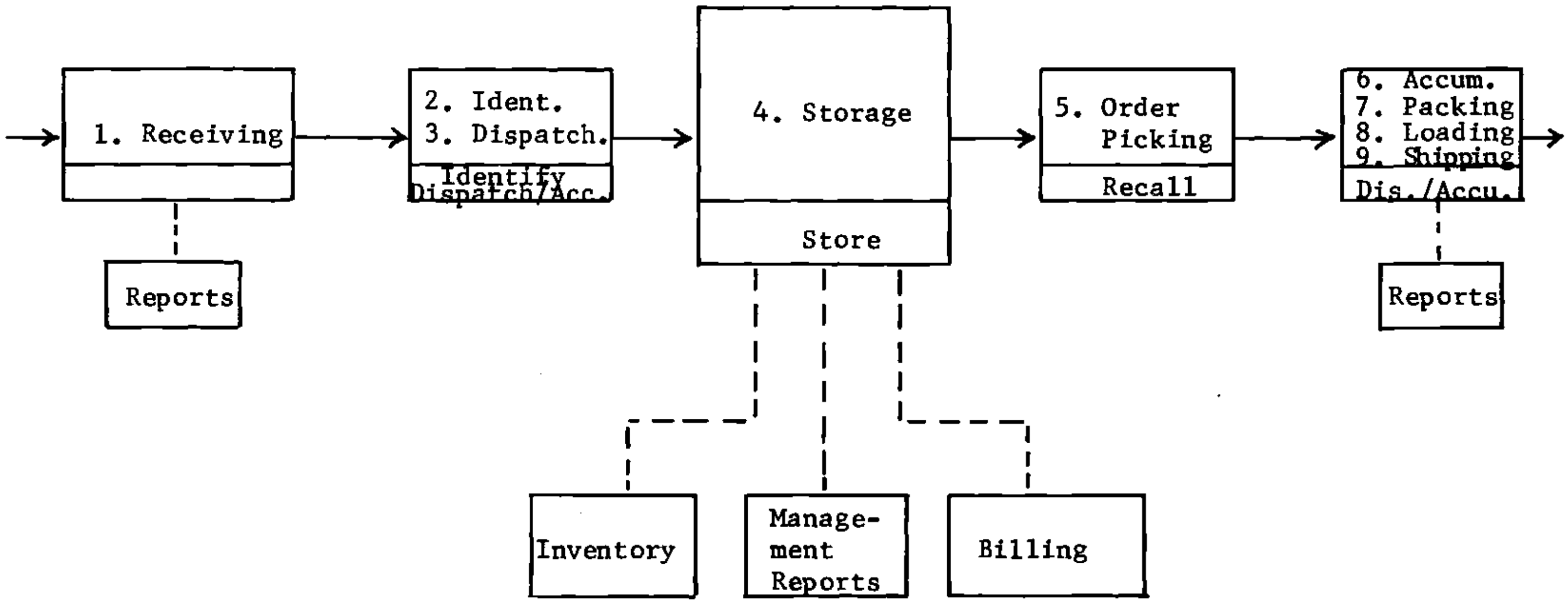

Figure 3. Relationship Between Activity Areas and Basic Control Functions.

touching the material (photoelectric and magnetic switches, proximity switches, etc.). These devices can identify an item by weight, size, color or chemical composition.

2. Dispatching/Accumulating

This function is closely related to the identification function. It uses the information from identifying devices, or from an operator keyboard, to sort and direct items to pre-selected locations. Dispatching can be done in two basic ways: read the identity of the item as it passes each conveyor exit (item memory) or identify the item at one point and "remember" its pre-selected location when it passes by it (control memory).

Item memory dispatching can be carried out by imprinting a code, such as a light-sensitive of magnetic coded pattern, on the item, its carrier or the conveyor, so that information for sorting each item travels with the item. In this setup, scanners at each exit compare the code with a pre-set pattern and, when the two match, a signal is sent to an actuator and the item is diverted to the proper location. The main advantage of this system is that an item can be removed from the conveyor at any time without destroying its code information.

Control memory dispatching requires that some form of memory be provided in the control system. The two basic types of memory are the synchronous (remembers the position of each item on the conveyor) and the sequential (remembers the sequence of the items on the conveyor). A device which remembers position on the conveyor can be: (1) a simultaneous shift register -- a group of relays or static logic elements so arranged as to provide for the transfer of information placed in one section to the next section, after a preselected lapse of time -- or, (2) a device synchronized with the conveyor. This device is "marked", so that as the item passes by its preselected exit, the destination "mark" reaches a reading head in the memory, and a signal is given to actuate a diverter.

The disadvantage of synchronous memory is that the accuracy may be affected by a stretch of the belt or by the presence of a gravity section on the take-away conveyor. Sequential memory is usually accomplished with a storage-type shift register. Its main disadvantage is that if one item is removed from the conveyor, the sequence is destroyed and the following items may be misdirected.

3. Store

This function represents a buffer between the input and output flow rates of the system. It is limited to accepting dispatched items, giving up recalled items, and counting items for inventory purposes. Items are stored in one of two ways: by assigned space or at random. The latter method allows more efficient utilization of the cube in the warehouse.

4. Recall

This function consists of retrieving items from storage. Although it appears to be the reverse of dispatching, it is not, because the item identification is already established simply by its location in the storage area. This function is essentially the order picking operation in a warehouse. It can be accomplished in one of three basic ways:

a. Manual. This is the simplest way to perform the recall function. The orders are picked by hand and then are delivered by one of several methods, such as placing on a conveyor or tractor-trailer train to be taken to the accumulation area.

b. Retrievers. These are special devices frequently similar in principle to the stacker crane. Items are stored in separate rack locations or pigeon-holes and are recalled one at a time. The method is most commonly used for heavy, awkward loads.

c. Flow racks are the usual approach to a fully automated recall function. Orders may be filled in one of three ways:

(1) one item at a time,

(2) one order at a time, or

(3) several orders at a time.

Several control techniques can be used to pick one or several orders at a time.

The simultaneous drop system can be used when there is no need to avoid collision of items on the take-away conveyor, such as in the case of picking cans or bottles.

The sequential recall system controls the flow racks in such a way that rack 1 is always picked before rack 2, rack 2 before rack 3, etc. In this manner, collision of items is avoided. Various decks of flow racks can also be picked in this fashion. In any case, the input information to the system should be presorted by sequence, unless the control system is able to sort the information.

The synchronous recall or "full conveyor" system picks orders by reserving a space on the take-away belt for each item before it is picked. The input information to the system (keyboard, punched cards or tape) can be fed in any order, and the items will be picked in the order in which the information is read. Since there is a spot reserved for each item on the conveyor by means of a shift register control, no danger of collision is present. For example, assume that the items to be picked are read into the control as 6, 6, 1, 4, 5, 3, 7. Then, just before releasing item 1, the take-away conveyor will look as in Figure 4. Carton 1 will then drop between 6 and 4, and a moment later, item 3 will drop between 5 and 7 as the space reserved for it comes by.

Conclusions

It has been relatively difficult in the past to justify the automation of warehousing functions since management had usually focused all its attention to the production end of the firm.

However, the increasing costs of distribution, competitive pressures and other reasons outlined in this Chapter have forced management to place more emphasis in the improvement of warehouse operations and related functions. Automation of warehouse operations has become one of the techniques management is now employing to effect improvements in the warehousing function.

The last section of this Chapter is summarized and expanded in Figure 5, which shows the wide range of techniques and basic equipment types utilized in the automation and mechanization of warehouse operations.

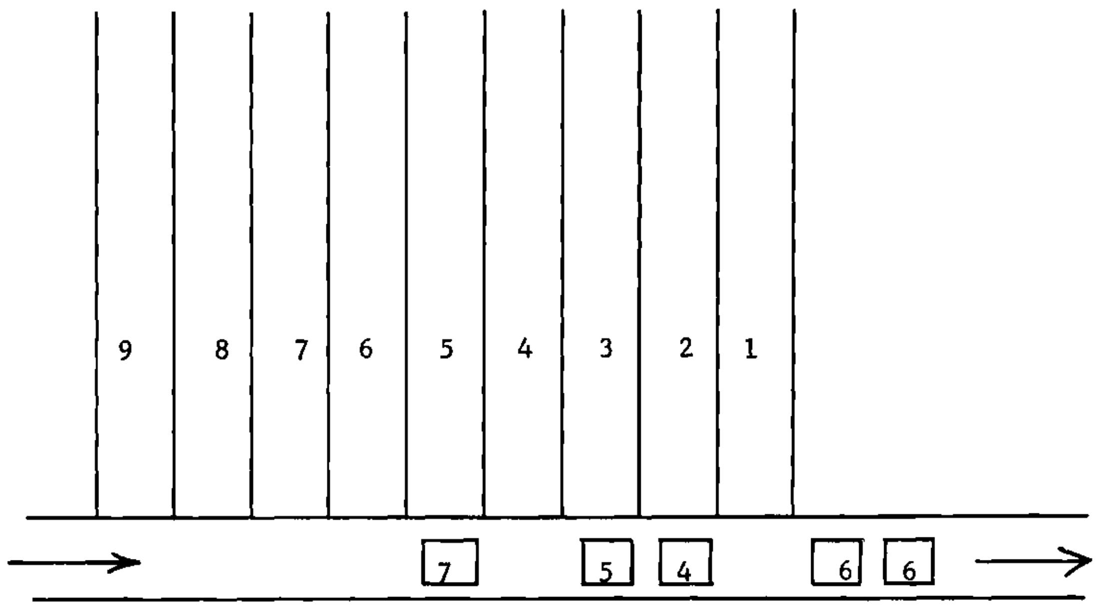

Figure 4. Synchronous Recall.

Activity Area	Techniques	Common Equip./Method
1. Receiving	Manual Mechanization	Carts Trucks Conveyors
2. Identification and Sorting	Visual or Manual Mechanization	Limit switches Photoelastic swt X-ray devices Actuators
3. Dispatching to storage	Item coding Container Coding Conveyor coding	Lift truck Tractor trailer Tow line Conveyor Crane or hoist Stacker Crane
4. Storage	Assigned space Random	On floor On shelf or bin On conveyor On fixed rack On flow rack
5. Order Picking	Simultaneous drop Sequential Synchronous	Lift truck Tractor trailer Tow line Conveyor Crane or hoist Stacker crane Retriever
6. Order accumulation	Mechanization	Lift truck Tractor trailer Tow line Conveyor Crane or hoist Stacker crane
7. Packing	Mechanization	Strapping machine Packing machine
8. Loading	Mechanization	Conveyors
9. Shipping	Usually manual	
10. Record keeping	Manual Automatic	Accounting mach. Computer

Figure 5. Techniques and Equipment Utilized to Mechanize and Automate Warehousing.

CHAPTER V

FACTORS INFLUENCING THE AUTOMATION DECISION

The decision of whether to install an automated handling system in a warehouse is one that can not be made lightly. Although a major reason for automating a warehouse is the expected savings in labor costs, it is not the only one, nor necessarily the most important, as was pointed out in the preceding chapter.

Many factors pertaining to each particular product and operation have a great influence on the outcome of this decision. However, these factors are so numerous that it is almost impossible to consider all of them during the planning stage of a warehouse design project. Lane (14) compiled and organized nearly one hundred of these factors into the following general classifications: Unit Handled, Function, Equipment, Operating Costs and Secondary Motives. Even this relatively small list is too extensive to consider all of them in a typical situation. For the purposes of this thesis, those factors considered most important were extracted from Lane's chart and an attempt was made to quantify them. A list of these factors appears in Figure 6.

A questionnaire was prepared and sent to the operators of over 40 automated warehouses in the United States for the purpose of collecting information needed for the quantification of these factors. The results of this survey, which are presented in the Appendix, were used to construct the charts that appear later on this chapter.

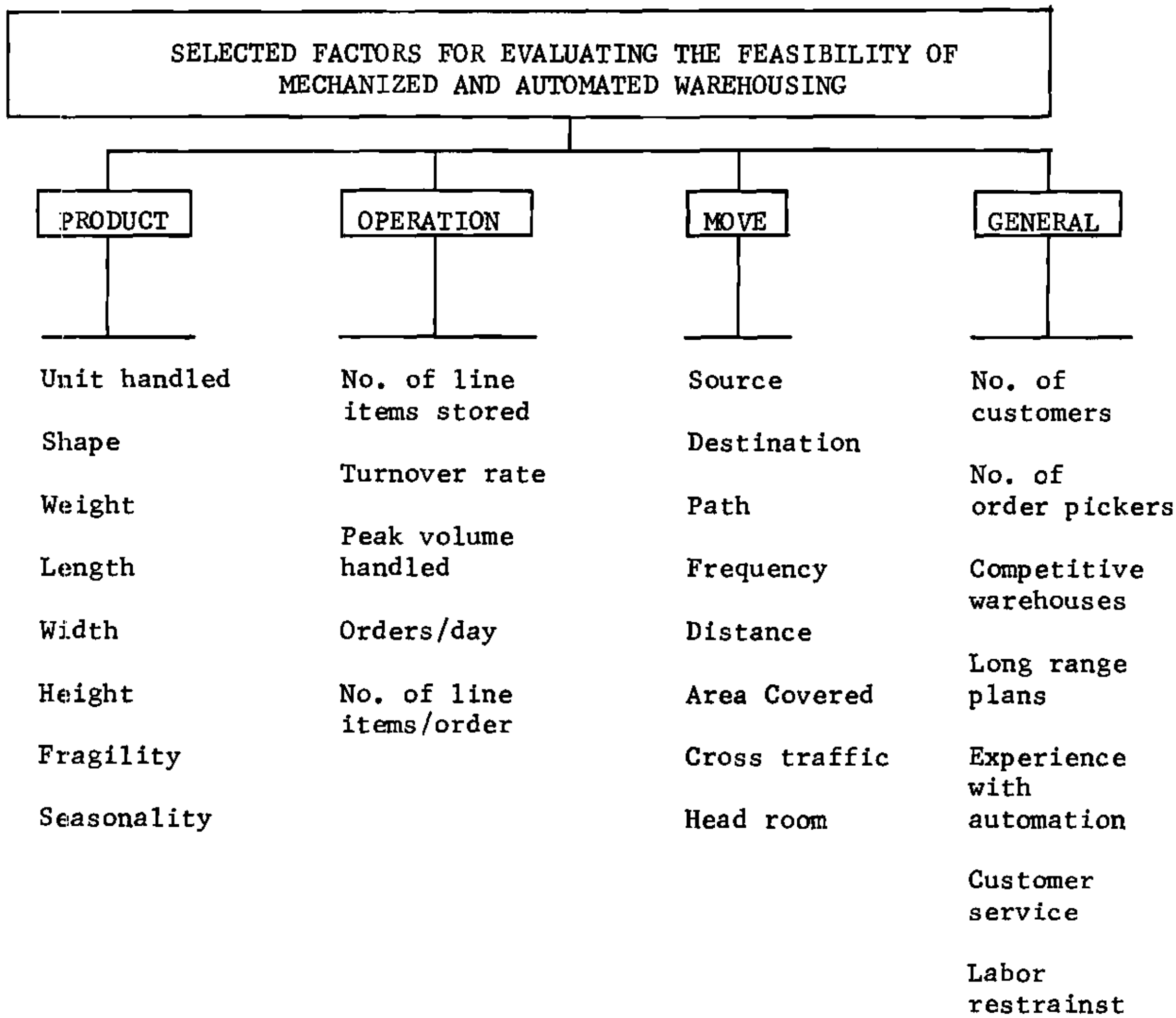

Figure 6. Selected Factors for Evaluating the Feasibility of Automated Warehousing.

Progressive Steps to Automation

Before discussing in detail the factors for consideration in analyzing and evaluating the feasibility of an automated warehousing operation, it seems worthwhile to examine the extent to which each operation or activity performed in a warehouse can be mechanized. The Levels of Mechanization apprach proposed by Bright (18) and described in Chapter II can be adapted to the warehouse situation, and a technique similar to his Mechanization Profile can be used to show the relationship between each warehouse activity and each level of mechanization.

The seventeen levels proposed by Bright have been reduced to nine levels or steps for the present purpose, as follows.

1. Hand

This level refers to the fully manual operation, where no equipment of any sort is used. The weight and size of the product are typical restrictions on pure manual handling. An example is manual packaging.

2. Hand Equipment

Handling performed with the aid of nonpowered equipment is included in this level. A platform truck is a typical example of the material handling equipment included in this classification.

3. Gravity Equipment

The equipment in this level employs the force of gravity as the means for accomplishing the move. Chutes, slides and roller conveyors can be considered under this category.

4. Powered Hand Equipment

In this step, mechanical power is applied to the equipment to supplement the operator's muscular efforts. Examples are the portable elevator and the manually-operated hoist.

5. Power Equipment, Hand Control

The difference between the preceding level and this one is that external power is applied to perform the handling. The operator's actions are limited to control of the amount and direction of the move within the area of operation of the equipment. Examples: the fork lift truck and the electrically-operated hoist.

6. Power Equipment, Program Control

It is implied in this level that the equipment is non-manually-operated and that external power is applied. This equipment operates through a predetermined sequence within definite space and speed limits, and with little or no aid from a human operator. A push-button programmed stacker crane is a typical example.

7. Power Equipment, Remote Control

The equipment included in this level has characteristics similar to those in the two preceding levels. The main difference is that the controls for the equipment are physically and geographically separated from the handling equipment. This feature makes possible the grouping of the controls of several equipments at one point, with the consequent reduction in number of operators needed. Examples are the overhead crane and remote-controlled order picking systems.

8. Sensing Equipment

The steps to automation described so far have one thing in common: a human operator is required to initiate action. In this level, the equipment is activated when it senses the entrance of the material into the handling system, then measures a preselected characteristic of the material and changes the speed, position or direction of the material according to the measurement. A sorting system, with its sensors and actuators, is an example of the equipment in this level.

9. Automated System Equipment

This last step in the mechanization hierarchy embodies those types of equipment which identify the material and are able to determine, without human control, the speed and direction of handling, and dispatch or select it from the storage location. An example is a computer-controlled random storage system.

The boundaries of the levels of mechanization defined above are vague and in some cases difficult to distinguish. For this reason, although it could be worthwhile to look at these levels separately, it has been decided, for the purposes of this study, to group the levels into three distinct classifications: Manual handling (levels 1, 2, 3, 4), Mechanized handling (5, 6, 7) and Automated handling (levels 8, 9). The treatment of the levels in this fashion will facilitate the identification of the relationships between the factors for analyzing a warehouse operation and the level of mechanization.

Following a procedure suggested by Bazaraa (27), two values were used to establish the relationship between each warehouse activity and the three levels of mechanization. These were: difficulty of the application and economics of the application. Four degrees of difficulty were chosen: (1) easy, (2) moderately difficult, (3) difficult, and (4) very difficult. Two possibilities were chosen with respect to the economics of applying techniques of a given level to a given activity:

(1) reasonable cost of application and (2) unreasonable cost of application. Figure 7 shows these relationships.

Although the chart in Figure 7 has been constructed in a subjective manner, it is based on information provided by the survey, and on the basis of a study of available literature on the design and operation of automated and mechanized warehouses in this country, and is, therefore, valid for the present purpose.

A look at the chart indicates that, of the nine activities concerned with the physical handling of materials in a warehouse, only five can be economically mechanized or automated at the present time. A closer look at these five activities reveals that dispatching and order accumulation are accomplished with similar types of equipment and in much the same manner. Therefore, only four distinct activities are considered prime candidates for mechanization and automation, and only these will be subjected to further analysis. These are: identification and sorting, storage, order picking or recall and dispatching-accumulation.

Description of the Factors

As previously stated, an attempt was made to quantify most of the factors listed in Figure 6. However, some factors such as frequency of the move and amount of cross traffic are relatively intangible, making a feasible quantification rather difficult. Those two factors, and other similar ones, were considered in this study, but no quantitative values were assigned to them.

A short description of the factors in Figure 6 follows.

A. Factors Related to the Product

1. Unit Handled. This factor refers to the type of unit that is

	Levels of Mechanization \ Warehouse Activities	1. Receiving	2. Identification & Sorting	3. Dispatching	4. Storage	5. Order Picking	6. Order Accumulation	7. Packing	8. Loading	9. Shipping
Manual	1. Hand	U1	U1	U1	U1	U1	U1	U1	U1	U1
	2. Hand equipment	U1	U1	U1	U1	U1	U1	U1	U1	U1
	3. Gravity equipment	R2	U1	R1	R1	U1	U1	R1	R1	R1
	4. Powered Hand Equipment	R2	R1	R1	R1	R1	R1	R1	R1	R1
Mech.	5. Power equip., hand control	R2	R1	R1	R2	R2	R1	R2	R2	R2
	6. Power equip., program control	R2	R2	R2	R3	R3	R2	U3	U3	R3
	7. Power equip., remote control	U3	R3	R3	R3	R3	R3	U4	U3	U3
Auto.	8. Sensing equipment	U4	R3	U4	U4	U4	R4	U4	U4	U4
	9. Automated systems equipment	U4	U4	U4	U4	U4	U4	U4	U4	U4

Cost

R - reasonable cost of application
U - unreasonable cost of application

Difficulty

1. Easy application
2. Moderately difficult application
3. Difficult application
4. Very difficult application

Figure 7. Relationship between the Levels of Mechanization and the Warehousing Activities.

being handled, that is, individual, case or pallet.

2. Shape. Indicates the general geometric shape of the unit being handled. The uniformity of the unit handled, that is, the percentage of regular and irregular units, is also important.

3. Weight. Refers to the maximum weight of the unit handled or stored.

4. Length. Indicates the dimension of the unit handled measured in a horizontal plane and parallel to the direction of the movement.

5. Width. Indicates the dimension of the unit measured in a horizontal plane, but perpendicular to the direction of the movement.

6. Height. The dimension of the unit handled measured vertically.

7. Fragility. This factor indicates the degree of resistance to scratch and breakage of the unit handled.

8. Seasonality. Refers to the percentage of the products that are seasonal.

B. Factors Related to the Operation

1. Number of Line Items Stored. This factor indicates the number of stock-keeping units stored in the warehouse.

2. Average Turnover Rate. This factor refers to the number of products handled per unit of time.

3. Peak Volume Handled. Similar to the preceding one, this factor indicates the peak quantity of units handled per unit of time.

4. Orders Per Day. Indicates the average number of orders handled in the warehouse in one day.

5. Number of Line Items Per Order. This factor indicates the average number of line items in an average order.

C. Factors Related to the Move

1. Source. This factor refers to the characteristics of the point from which the move originates.

2. Destination. Refers to the characteristics of the point at which the move terminates.

3. Path. This factor indicates the variability of the path over which the units are being moved.

4. Distance. Refers to the length of the move measured along the path, from the point of origin to the point of destination.

5. Frequency. Indicates the number of occurrences per unit of time, of the move.

6. Area Covered. This factor relates to the size of the area in which the unit is being handled.

7. Cross Traffic. Refers to the amount of permissible interference to the movement of the material.

8. Head Room. Indicates the vertical distance, measured from the floor, available to move the material.

D. Factors Under the Term General

1. Number of Customers. This factor indicates the average number of customers the warehouse serves.

2. Number of Order Pickers. Indicates the number of employees performing picking operations in the warehouse.

3. Competitive Warehouses. This factor indicates the number of competitors that have mechanized or automated their warehouses.

4. Long Range Location Plans. Refers to the future plans of the company with respect to the location of their warehouses.

5. Experience with Automation. Indicates the breadth of the company's experience with automation programs. That is, to what extent has the company applied automation to other areas of the business, such as production and data processing.

6. Customer Service. Indicates the present level of quality of customer service.

7. Labor Restraints. Indicates the amount of freedom, from labor restraints, to initiate an automation program.

Conclusions

The relationships between all of the preceding factors and the three levels of mechanization (Manual, Mechanized and Automated) are presented in chart form on the following pages. Figures 8 and 9 show these relationships for the Identification and Sorting activity, Figures 10 and 11 show it for the Storage activity, Figures 12 and 13 for the Order Picking activity and Figures 14 and15 for the Dispatching-Accumulation activities.

The factors were divided into two arbitrary classifications: primary and secondary. The primary factors are those directly related to the product characteristics and operation statistics. The secondary factors include those related to the characteristics of the business and other intangible factors.

FACTORS			LEVEL OF MECHANIZATION: Manual	Mechanized	Automated
PRODUCT	Shape	irregular	X		
		0-50% reg.		X	
		50-100% reg.			X
	Weight	1-50#	X	X	X
		50-200#		X	X
		200-1000#		X	
		1000-10000#		X	
	Length	1-3 ft.	X		X
		3-5 ft.		X	X
		5-20 ft.		X	
	Width	1-3 ft.	X		X
		3-5 ft.		X	X
		5-20 ft.		X	
	Height	1-3 ft.	X		X
		3-5 ft.		X	X
		5-10 ft.		X	
	Fragility	fragile	X		
		0-25% is fragile		X	X
		0-50% is fragile		X	
	Seasonality	seasonal	X		
		0-25% is seasonal		X	X
		0-50% is seasonal		X	
	Unit	individual item	X	X	
		case	X	X	X
		unit load	X	X	
OPERATION	No. of line items stor.	1-200			X
		200-3000		X	X
		3000-10000		X	
		over 10000	X		
	Cases/day (avg)	1-2000	X		
		2000-8000		X	
		over 8000			X
	Cases/hour (peak)	1-200	X		
		200-1000		X	
		over 1000			X
	Orders/day	1-100	X	X	
		100-300		X	X
		over 300	X	X	

Figure 8. Relationship between the Levels of Mechanization and the Primary Factors in Analyzing Automated Warehousing - Identification and Sorting Activity.

FACTORS		LEVEL OF MECHANIZATION Manual	Mechanized	Automated
No. of customers	1-100	na	na	na
	100-2000	na	na	na
	over 2000	na	na	na
No. of line items/order	1-40			X
	40-200		X	
	over 200	X		
No. of order pickers	1-6	na	na	na
	7-15	na	na	na
	over 15	na	na	na
Competitor warehouses	none automated	X		
	some automated		X	
	many automated			X
Long range location plan	change expected	X	X	
	possible change		X	
	no change			X
Experience with automat.	none	X		
	some		X	X
	wide			X
Customer service	good	X	X	
	satisfactory		X	
	not satisfactory			X
Freedom from labor restraint	none	X		
	some		X	
	yes			X

NOTE: na = not applicable.

Figure 9. Relationship Between the Levels of Mechanization and the Secondary Factors in Analyzing Automated Warehousing - Identification and Sorting Activity.

FACTORS			LEVEL OF MECHANIZATION		
			Manual	Mechanized	Automated
PRODUCT	Shape	irregular	X		
		0-50% reg.		X	
		50-100% reg.			X
	Weight	1-50#	X	X	X
		50-200#		X	X
		200-1000#		X	X
		1000-10000#		X	
	Length	1-3 ft.	X		X
		3-5 ft.		X	X
		5-20 ft.		X	
	Width	1-3 ft.	X		X
		3-5 ft.		X	X
		5-20 ft.		X	
	Height	1-3 ft.	X		X
		3-5 ft.		X	X
		5-10 ft.		X	
	Fragility	fragile	X		
		0-25% is fragile		X	X
		0-50% is fragile		X	
	Seasonality	seasonal	X		
		0-25% is seasonal		X	X
		0-50% is seasonal		X	
	Unit	individual item	X		
		case	X	X	X
		unit load		X	X
OPERATION	No. of line items stor.	1-200			X
		200-3000			X
		3000-10000		X	
		over 10000	X		
	Cases/day (avg)	1-2000	X		
		2000-8000		X	
		over 8000			X
	Cases/hour (peak)	1-200	X		
		200-1000		X	X
		over 1000			X
	Orders/day	1-100	X		
		100-300		X	
		over 300			X

Figure 10. Relationship between the Levels of Mechanization and the Primary Factors in Analyzing Automated Warehousing - Storage Activity.

FACTORS		Manual	Mechanized	Automated
		LEVEL OF MECHANIZATION		
No. of customers	1-100	X		
	100-2000		X	
	over 2000			X
No. of line items/order	1-40	na	na	na
	40-500	na	na	na
	over 500	na	na	na
No. of order pickers	1-6	na	na	na
	7-15	na	na	na
	over 15	na	na	na
Competitor warehouses	none automated	X		
	some automated		X	
	many automated			X
Long range location plan	change expected	X	X	
	possible change		X	
	no change			X
Experience with automat.	none	X		
	some		X	X
	wide			X
Customer service	good	X	X	
	satisfactory		X	
	not satisfactory			X
Freedom from labor restraint	none	X		
	some		X	
	yes			X

NOTE: na = not applicable.

Figure 11. Relationship between the Levels of Mechanization and the Secondary Factors in Analyzing Automated Warehousing - Storage activity.

FACTORS			LEVEL OF MECHANIZATION		
			Manual	Mechanized	Automated
PRODUCT	Shape	irregular	X		
		0-50% reg.		X	
		50-100% reg.			X
	Weight	1-50#	X	X	X
		50-500#		X	
		500-1000#		X	
		1000-10000#		X	
	Length	1-3 ft.	X		X
		3-5 ft.		X	
		5-20 ft.	X	X	
	Width	1-3 ft.	X		X
		3-5 ft.		X	
		5-20 ft.	X	X	
	Height	1-3 ft.	X		X
		3-5 ft.		X	
		5-10 ft.	X	X	
	Fragility	fragile	X		
		0-25% is fragile			X
		0-50% is fragile		X	
	Seasonality	seasonal	X		
		0-25% is seasonal			X
		0-50% is seasonal		X	
	Unit	individual item	X		
		case	X	X	X
		unit load		X	
OPERATION	No. of line items stor.	1-200			X
		200-3000		X	
		3000-10000		X	
		over 10000	X		
	Cases/day (avg)	1-2000	X		
		2000-8000		X	
		over 8000			X
	Cases/hour (peak)	1-200	X		
		200-1000		X	
		over 1000			X
	Orders/day	1-100	X		
		100-300		X	
		over 300			X

Figure 12. Relationship between the Levels of Mechanization and the Primary Factors in Analyzing Automated Warehousing - Order Picking Activity.

		LEVEL OF MECHANIZATION		
FACTORS		Manual	Mechanized	Automated
No. of customers	1-100	X		
	100-2000		X	
	over 2000			X
No. of line items/order	1-40			X
	40-500		X	
	over 500	X		
No. of order pickers	1-6	X		
	7-15		X	
	over 15			X
Competitor warehouses	none automated	X		
	some automated		X	
	many automated			X
Long range location plan	change expected	X	X	
	possible change		X	
	no change			X
Experience with automat.	none	X		
	some		X	X
	wide			X
Customer service	good	X	X	
	satisfactory		X	
	not satisfactory			X
Freedom from labor restraint	none	X		
	some		X	
	yes			X

Figure 13. Relationship between the Levels of Mechanization and the Secondary Factors in Analyzing Automated Warehousing - Order Picking Activity.

			LEVEL OF MECHANIZATION		
FACTORS			Manual	Mechanized	Automated
PRODUCT	Shape	irregular	X		
		0-50% reg.		X	
		50-100% reg.			X
	Weight	1-50#	X		X
		50-500#		X	
		500-1000#		X	
		1000-10000#		X	
	Length	1-3 ft.	X		X
		3-5 ft.		X	X
		5-20 ft.		X	
	Width	1-3 ft.	X		X
		3-5 ft.		X	X
		5-20 ft.		X	
	Height	1-3 ft.	X		X
		3-5 ft.		X	X
		5-10 ft.		X	
	Fragility	fragile	X		
		0-25% is fragile			X
		0-50% is fragile		X	
	Seasonality	seasonal	X		
		0-25% is seasonal			X
		0-50% is seasonal		X	
	Unit	individual item	X		
		case	X	X	X
		unit load		X	
OPERATION	No. of line items stor.	1-200			X
		200-3000			X
		3000-10000		X	
		over 10000	X		
	Cases/day (avg)	1-2000	X		
		2000-8000		X	
		over 8000			X
	Cases/hour (peak)	1-200	X		
		200-1000		X	
		over 1000			X
	Orders/day	1-100	X		
		100-300		X	
		over 300			X

Figure 14. Relationship between the Levels of Mechanization and the Primary Factors in Analyzing Automated Warehousing - Dispatching and Accumulation Activities.

FACTORS		LEVEL OF MECHANIZATION: Manual	Mechanized	Automated
No. of customers	1-100	X		
	100-2000		X	
	over 2000			X
No. of line items/order	1-40			X
	40-500		X	
	over 500	X		
No. of order pickers	1-6	na	na	na
	7-15	na	na	na
	over 15	na	na	na
Competitor warehouses	none automated	X		
	some automated		X	
	many automated			X
Long range location plan	change expected	X	X	
	possible change		X	
	no change			X
Experience with automat.	none	X		
	some		X	X
	wide			X
Customer service	good	X	X	
	satisfactory		X	
	not satisfactory			X
Freedom from labor restraint	none	X		
	some		X	
	yes			X

NOTE: na = not applicable.

Figure 15. Relationship between the Levels of Mechanization and the Secondary Factors in Analyzing Automated Warehousing - Dispatching and Accumulating Activities.

CHAPTER VI

PROCEDURE FOR DEVELOPING AN AUTOMATED WAREHOUSE

The analysis of the feasibility of automating or mechanizing a given warehouse activity, or group of related activities, can be very difficult. Such an analysis requires a person with knowledge of both automation and warehouse operation, and with experience in integrating the two. It also requires a systematic procedure that takes into account all pertinent factors.

Basically, the design of an automated warehouse consists of searching for an optimum design among those that satisfy the objectives and restrictions imposed by management and by the present state of technology. This optimum design can be reached in a number of possible ways, but what is considered a preferred general procedure is presented in this chapter.

Phases of the Design Procedure

The procedure for developing an automated warehouse consists of the following five major stages: (1) formulation, (2) analysis, (3) decision, (4) specification, and (5) implementation. A flow chart of the procedure is shown in Figure 16.

1. Formulation Phase

A common tendency of engineers when solving a problem is immediately thinking in terms of improvements of the present situation. This approach is totally wrong, inasmuch as the engineer will concentrate on

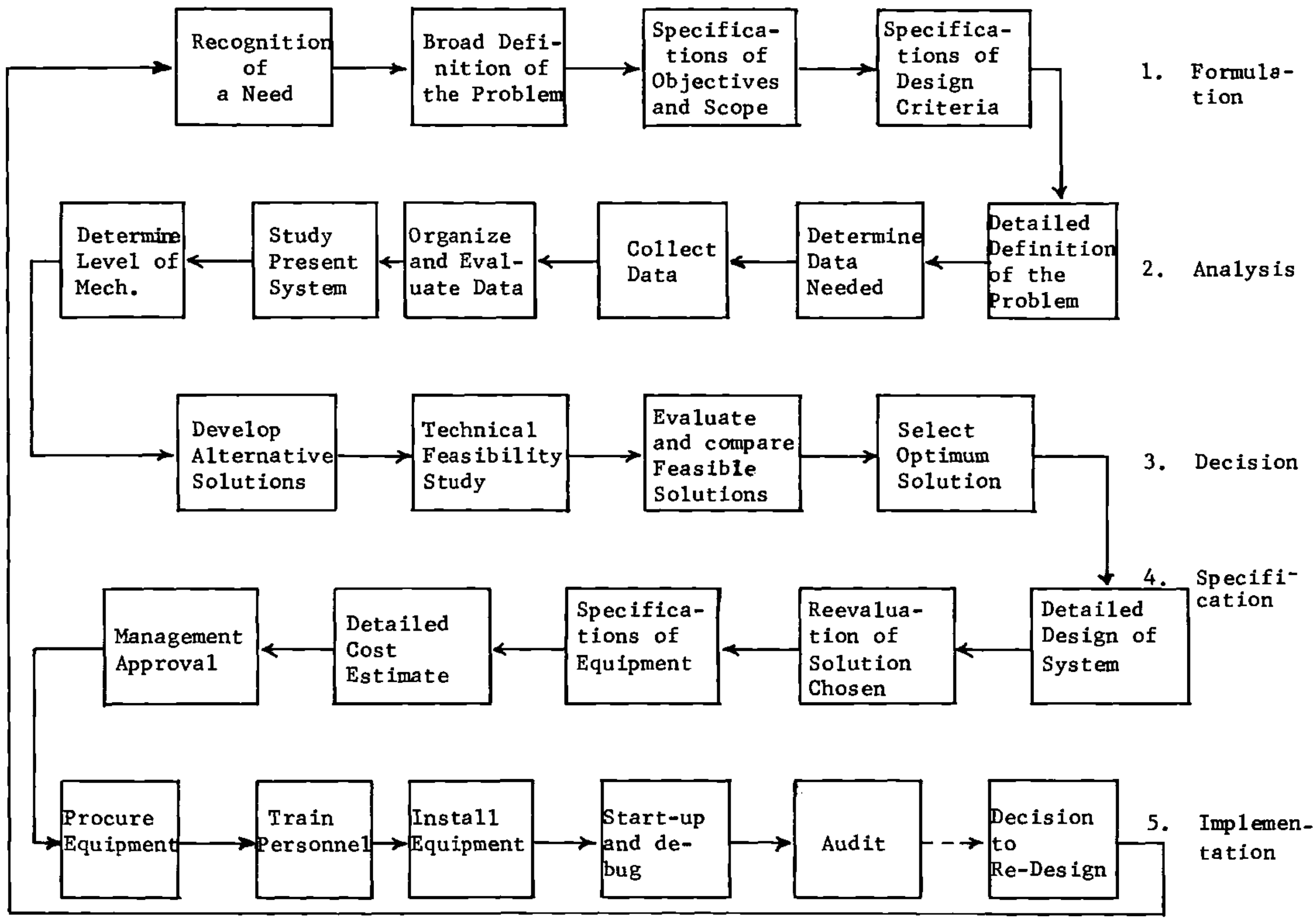

Figure 16. The Design Cycle.

the present solution instead of the problem itself. Therefore, the first phase in the procedure should be the formulation of the problem.

The importance of defining the problem and establishing its scope and restrictions as early in the process as possible cannot be overemphasized. The actual breadth of the definition of the problem is a prerogative of the engineer, but it should be as general as possible.

During this phase, the objectives to be accomplished with the installation of an automated warehouse should be specified. These could be lower handling costs, reduced inventory, faster service to customers, or all three.

Finally, appropriate design criteria for measuring the effectiveness of each solution developed during the subsequent phases should be selected now. Common criteria appropriate to the warehouse situation are:

a. Overall cost of system,

b. Return on investment,

c. Increase in productivity,

d. Flexibility,

e. Safety,

f. Reliability,

g. Ease of maintenance,

h. Utilization of floor space,

i. Amount of damage to product expected (or permissible),

j. Quality of customer service,

k. Ease of inventory control, and

l. Public relations value.

Each of these should receive different emphasis according to its importance to the problem.

The engineer should also bear in mind that the analysis of the warehouse should be conducted one activity or function at a time, and then these individual solutions should be integrated into a total warehousing system. This integrated system will consist then of the handling functions, the storage function, and the data processing function, which includes accounting, order entry, inventory control, invoicing, billing, and management reports.

2. Analysis Phase

Once the problem has been formulated in terms of the functions to be performed and the restrictions and criteria to be met, the engineer can proceed to define the problem in detail. This detailed definition is necessary to ascertain what type of information is needed for further analysis.

In a warehouse, the data needed have to do with product parameters and move characteristics, such as those outlined in Chapter V. The next step is the collection, organization and evaluation of these data.

Generally, a warehouse operation can be improved in any of the following ways:

a. Improve the present activities through a work simplification or methods engineering study.

b. Improve some activities and mechanize others.

c. Mechanize all activities.

d. Mechanize some activities and automate others.

e. Automate all activities.

These successive steps suggest that the best solution might well be a combination of the advantages of manned operations with the advantages of mechanized and automated operations. Referring to Figures 8 through 15, the appropriate level of mechanization, based on the data gathered, can be determined for each warehouse activity.

3. Decision Phase

This is the most important phase in the proposed procedure. During this phase, a set of feasible alternative solutions is developed and an optimum solution is chosen from this set. The complexity of this task indicates that a team or group approach to the problem will be advantageous. Consultants and automatic equipment manufacturers should be called in to work closely with the company personnel. Complete cooperation and exchange of ideas at this time will lead to the ultimate success of the installation.

The step-by-step procedure during this phase is:

a. Conceptualize and accumulate as many alternative systems as possible for each activity.

b. Determine the practical and technical feasibility of each alternative system and eliminate the unfeasible. Evaluate solutions by judging against system criteria.

c. Select tentative types of equipment for each feasible solution.

d. Make an economic comparison of each feasible system with the present solution. Evaluate the intangible benefits of each solution.

e. Select the most economical system for each activity.

f. Integrate the individual systems into an overall system.

The development of alternative solutions should take into consideration future requirements as well as present requirements. In many cases, a "piecemeal" approach to automation might be desirable. That is, the proposed system, although possibly not completely automated in itself, should be designed in such a way that additions in the future will improve it without a need for major alterations.

It should be recognized also that it is generally found that 15 to 20 per cent of the items in a warehouse account for 70 to 80 per cent of the warehouse activity. Therefore, by stratifying the items into groups depending on their activity, different levels of mechanization, can be applied to the same activity. For example only 20 per cent of the items could be picked automatically, while the remaining are picked manually or with the aid of mechanized equipment.

A major question that arises during the search for alternatives is whether the control should be a logic device or a computer. Generally, a computer is economical when the equipment selected is highly mechanized or automated and when there exist other functions that can be performed with the aid of a computer, such as the accounting and inventory control functions. Whether a computer is considered or not, it is important to recognize that the handling system and the data processing (information) system should be designed as one project.

The selection of materials handling equipment to accomplish the various warehouse activities is an extremely difficult process. The number of types of equipment and methods available to perform these activities is so great that it is almost impossible to select the best type of equipment for a given activity. To aid the engineer in selecting the equipment for a warehouse, five charts have been prepared which relate the product characteristics factors and the material and move parameters identified during the course of this study (see Figure 6) to the most common pieces of equipment found in mechanized warehouses today. These charts are shown as Figures 17, 18, 19, 20, and 21.

The best systems for each activity should be integrated into a total system and an evaluation made to insure that a system which is optimal for one activity will not create problems in another activity.

4. Specification Phase

A detailed design of the integrated system chosen will initiate the specification phase of the procedure. The design should be reevaluated constantly, as it progresses, against the criteria and objectives.

The specifications for the system should be sent to several vendors for bids. The vendors should be selected based on cost, ability and on an evaluation of the proposals against design criteria.

A final report, including a detailed cost estimate and detailed design, should be prepared and presented to management for approval. With management approval, the design of the system is completed.

5. Implementation Phase

During the installation of the system the designer should work closely with the supplier to insure adherence to specifications and to detect and remedy details that are incorrect or omitted.

The successful introduction of an automated warehouse operation in a company depends on the attitude of the labor force. Therefore, proper orientation of personnel will prove invaluable. Equally important is the development of operating procedures and the establishment of a training program for operation and maintenance personnel.

The designer should also take part in starting up the system and

Factors	Methods of Storage	Indiv. or Case					Unit Load			With Retriever
		Floor	Shelf	Fixed Rack	Flow Rack	Conveyor	Floor	Fixed Rack	Flow Rack	
Shape	Irregular	X	X							
	Regular		X	X	X	X	X	X	X	X
Weight	1-50#		X	X	X	X				
	50-500#	X		X		X	X	X	X	X
	500-1000#	X					X			X
	1000-10000#	X					X			X
Length	1'-3'		X	X	X	X				
	2'-5'	X		X			X	X	X	X
	5'-20'	X					X			
Width	1'-3'		X	X	X	X				
	2'-5'	X		X			X	X	X	X
	5'-20'	X					X			
Height	1'-3'		X	X	X	X				
	2'-5'	X		X			X	X	X	X
	5'-10'	X					X			
Fragility	Fragile		X	X				X		X
	Sturdy	X	X	X	X	X	X	X	X	X
Season-ality	Seasonal									
	Non-Seas.			na				na		X
Unit	Individual	X	X	X	X					
	Case			X	X	X	X	X	X	
	Unit Load						X	X	X	
Orders/Day	1-1200	X	X	X			X			
	2000-4000		X	X		X		X		X
	Over 4000				X	X			X	X

NOTE: na = not applicable.

Figure 17. Relationship between the Product Factors and the Storage Methods.

Product Factors \ Methods of Order Picking		Hand Truck	Mechanized: Lift Truck	Tractor-Tr. Train	Tow Line	Conveyor	Crane or Hoist	Stacker Crane	Auto.: Retriever or Storage Mach.	Convey. System
Unit	individ.	X				X	X	X	X	X
	case	X	X	X	X	X		X	X	X
	pallet		X					X		
Shape	irregular	X	X				X	X		
	regular	X	X	X	X	X		X	X	X
Weight	1-50#	X				X				X
	50-500#		X	X	X			X	X	X
	500-1000#		X	X			X	X		
	1000-10000#						X	X		
Length	1'-3'	X				X			X	X
	2'-5'	X	X	X	X	X	X	X	X	
	5'-20'						X			
Width	1'-3'	X				X			X	X
	2'-5'	X	X	X	X		X	X	X	
	5'-20'						X			
Height	1'-3'	X				X			X	X
	2'-5'	X	X	X	X		X	X	X	
	5'-10'						X			
Fragility	fragile	X		X	X			X	X	
	sturdy		X	X	X	X	X	X	X	X
Seasonality	seasonal	X	X	X	X	X	X	X		
	non-seas.	X							X	X

Figure 18. Relationship between the Product Factors and the Order Picking Method.

Operation and Move Factors \ Methods of Order Picking		Hand Truck	Mechanized: Lift Truck	Mechanized: Tractor Tr. Train	Mechanized: Tow Line	Mechanized: Conveyor	Mechanized: Crane or Hoist	Mechanized: Stacker Crane	Auto.: Retriever or Stg. Machine	Auto.: Conveyor. Sys.
Cases/Day	1-2000	X	X							
	2000-4000		X	X	X	X	X	X		
	over 4000							X	X	X
Cases/Hr. (Peak)	1-200	X				X				
	200-1200		X	X	X	X	X	X		
	over 1200							X	X	X
Orders/Day	1-100	X	X				X			
	100-300		X	X	X	X	X	X		
	300-600							X	X	X
Source	Fixed				X	X			X	X
	Any	X	X	X			X	X		
Destina-tion	Fixed				X	X			X	X
	Any	X	X	X			X	X		
Path	Simple	X			X	X				X
	Multiple		X				X			
	Variable		X	X			X	X	X	
Frequency	Irreg.	X	X	X			X	X		
	Unpred.	X	X				X			
	Cont.				X	X			X	X
	Inter.	X	X	X	X	X	X	X		
Distance	10'-100'	X	X				X	X	X	X
	over 100'		X	X	X	X	X	X		X
Area Covered	Fixed				X	X	X	X	X	X
	Variable	X	X	X						
Cross Traffic	None	X				X				X
	Low	X	X	X	X		X	X	X	
	High		X	X			X	X		
Head Room	4'-10'	X			X	X				X
	Over 10'	X	X	X	X		X	X	X	

Figure 19. Relationship between the Operation and Move Factors and the Order Picking Method.

Product Factors	Equipment for Dispatching and Sorting	Dispatching/Accum.						Ident. & Sorting		
		Lift Truck	Tractor Tr. Train	Tow Line	Conveyor	Crane or Hoist	Stacker Crane	Manual or Visual	Mechanized	Automated
Unit	individual				X	X	X	X	X	
	case	X	X	X	X		X	X	X	X
	pallet	X					X	X		
Shape	irregular	X				X	X	X		
	regular	X	X	X	X		X		X	X
Weight	1-50#				X			X	X	X
	50-500#	X	X	X			X	X	X	
	500-1000#	X	X			X	X	X		
	1000-10000#					X	X	X		
Length	1'-3'			X	X					X
	2'-5'	X	X	X	X	X	X	X	X	
	5'-20'					X		X		
Width	1'-3'				X					X
	2'-5'	X	X	X		X	X	X	X	
	5'-20'					X		X		
Height	1'-3'				X					X
	2'-5'	X	X	X		X	X	X	X	
	5'-10'					X		X		
Fragility	fragile		X	X			X	X		
	sturdy	X	X	X	X	X	X	X	X	X
Seasonality	seasonal	X	X	X	X	X	X	X	X	
	non-seasonal							X	X	X

Figure 20. Relationship between the Product Factors and the Identification, Sorting, Dispatching and/or Accumulating Equipment.

Equipment for Dispatching and Sorting / Operation and More Factors		Cases/Day			Cases/Hr (Peak)			Orders/Day			Source		Destination		Path			Frequency				Distance		Area Covered		Cross Traffic			Head Room	
		1-2000	2000-4000	over 4000	1-200	200-1200	over 1200	1-100	100-300	300-600	Fixed	Any	Fixed	Any	Simple	Multiple	Variable	Irregular	Unpred.	Continuous	Intermit.	10'-100'	Over 100'	Fixed	Variable	None	Low	High	4'-10'	Over 10'
Dispatching/Accum	Lift Truck	X	X			X		X	X			X		X		X	X	X	X		X	X	X		X		X	X		X
	Tractor Tr. Train		X			X			X			X		X			X	X			X		X		X		X	X		X
	Tow Line		X			X			X		X		X		X					X	X		X	X			X		X	X
	Conveyor		X		X	X			X		X		X		X					X	X		X	X		X			X	
	Crane or Hoist	X			X			X				X		X		X	X	X	X		X	X	X	X			X	X		X
	Stacker Crane		X	X		X	X		X	X		X		X			X	X			X	X	X	X				X		X
Identifi. & Sorting	Manual or Vis.	X			X			X	X			X		X	X		X	X	X			X	X					X		X
	Mechanized		X			X			X	X		X		X	X	X				X	X	X		na	na		X	X		X
	Automated		X	X		X	X			X	X		X		X	X				X		X				X			X	X

NOTE: na = not applicable.

Figure 21. Relationship between the Operation and Move Factors and the Identification, Sorting, Dispatching and/or Accumulating Equipment.

in "de-bugging" it. After the system is finally working correctly, it should be scruntinized periodically by the designer to insure that it is being operated as intended. The design cycle will be completed when, after the system has been working for a period of time, it is decided that redesign will be profitable. The process of finding a better solution will again be started, beginning with phase 1.

Case Study

The application of this procedure can be illustrated with the aid of an example. An analysis of a hypothetical warehousing operation will be conducted to show the use of the charts developed in this thesis. It is assumed that management has established the objectives and selected the proper criteria from a list similar to the one given earlier. The data collected from the present operation are presented on the form shown in Figure 22.

After collecting and organizing the data, it is necessary to determine the appropriate level of mechanization for each function. Referring to Figures 8 through 15, the number of "X" marks opposite the parameters which match the problem data (see Figure 23 for an example) is counted and tabulated for each of the three levels given. The level with the largest number of "X" marks is the appropriate level for each of the activities under study, as shown below.

	Ident. & Sorting	Storage	Order Picking	Dispat./accum.
Manual	4	5	5	5
Mechanized	11	8	11	8
Automated	10	9	8	9

Warehouse Analysis Sheet

Basic Data Required

Company______________________________ Plant____________________

Compiled by___________________________ Date____________________

Statement of the problem____

____

Product

Unit.	individual items
Shape	less than 50% regular
Weight.	30 lbs
Length.	3 feet
Width	2 feet
Height.	3 feet
Fragility	less than 50% are fragile
Seasonality	seasonal product

Operation

Number of line items stored	400
Turnover rate	7000 cases/day
Peak volume	1100 cases/hour
Orders per day.	150
Number of line items per order.	50

Move

Source.	fixed
Destination	any
Path.	variable, multiple
Frequency	intermittent
Distance.	80 feet
Area covered.	fixed
Cross traffic	high
Head room	25 feet

General

Number of customers	90
Number of order pickers	8
Number of competitors with automated warehouses	many
Long range location plans	change expected
Experience with automation.	some
Customer service level.	satisfactory
Freedom from labor restraints	yes

Figure 22. Example of a Data Collection Form.

FACTORS			LEVEL OF MECHANIZATION		
			Manual	Mechanized	Automated
PRODUCT	Shape	irregular	X		
		0-50% reg.		X	
		50-100% reg.			X
	Weight	1-50#	X		X
		50-500		X	
		500-1000#		X	
		1000-10000#		X	
	Length	1-3 ft.			X
		3-5 ft.		X	X
		5-20 ft.		X	
	Width	1-3 ft.			X
		3-5 ft.		X	X
		5-20 ft.		X	
	Height	1-3 ft.			X
		3-5 ft.		X	X
		5-10 ft.			X
	Fragility	fragile		X	
		0-25% is fragile			X
		0-50% is fragile		X	
	Seasonality	seasonal	X		
		0-25% is seasonal			X
		0-50% is seasonal		X	
	Unit	individual item	X	X	
		case	X	X	X
		unit load		X	
OPERATION	No. of line items stor.	1-200			X
		200-3000			X
		3000-10000		X	
		over 10000	X		
	Cases/day (avg)	1-2000	X		
		2000-8000		X	
		over 8000			X
	Cases/hour (peak)	1-200	X		
		200-1000		X	
		over 1000			X
	Orders/day	1-100	X		
		100-300		X	
		over 300			X
			3	4	6

Figure 23. Example of a Dispatching/Accumulating Activity Analysis - Levels of Mechanization versus Primary Factors.

The results of the analysis reveal that the Identification and Sorting activity and the Order Picking activity are likely candidates for mechanization, while the Storage activity and the Dispatching/Accumulation activities are candidates for automation.

The next step is to develop alternative solutions using the types of equipment suggested by the charts in Figures 17 through 21. The procedure is similar to the one just described. The number of "X" marks is counted (see Figure 24 for an example) and tabulated for each of the types of equipment shown in the charts.

Identification and Sorting Activity

Manual or visual	11
Mechanized equipment	12
Automated equipment	11

Storage Method

Floor	3
Shelf	7
Fixed rack	6
Flow rack	7
Conveyor	6

Order Picking Activity

Hand truck	10
Lift truck	12
Tractor trailer	9
Tow line	8
Conveyor	12
Crane or hoist	14
Stacker crane	14
Storage machine	12
Automated conveyor	10

Dispatching/Accumulation Activities

Lift truck	12
Tractor trailer	9
Tow line	8
Conveyor	12
Crane or hoist	12
Stacker crane	15

Operation and Move Factors \ Equipment for Dispatching and Sorting		Dispatching/Accum: Lift Truck	Tractor Tr. Train	Tow Line	Conveyor	Crane or Hoist	Stacker Crane	Iden. & Sorting: Manual or Vis.	Mechanized	Automated
Cases/Day	1-2000	X				X		X		
	2000-4000	X	X	X	X		X		X	X
	Over						⊗			⊗
Cases/Hr. (Peak)	1-200				X	X		X		
	200-1200	⊗	⊗	⊗	⊗		⊗		⊗	⊗
	Over 1200						X			X
Orders/Day	1-100	X				X		X		
	100-300	⊗	⊗	⊗	⊗		⊗	⊗	⊗	
	300-600						X		X	X
Source	Fixed			⊗	⊗					⊗
	Any	X	X			X	X	X	X	
Destina-tion	Fixed			X	X					X
	Any	⊗	⊗			⊗	⊗	⊗	⊗	
Path	Simple			X	X			X	X	X
	Multiple	⊗				⊗			⊗	⊗
	Variable	⊗	⊗			⊗	⊗	⊗		
Frequency	Irregular	X	X			X	X	X		
	Unpredict.	X				X			X	X
	Continuous			X	X				X	X
	Intermit.	⊗	⊗	⊗	⊗	⊗	⊗		⊗	
Distance	10'-100'	⊗				⊗	⊗	⊗	⊗	⊗
	Over 100'	X	X	X	X	X	X	X		
Areas Covered	Fixed			⊗	⊗	⊗	⊗		na	
	Variable	X	X						na	
Cross Traffic	None				X					X
	Low	X	X	X		X	X		X	
	High	⊗	⊗			⊗	⊗	⊗	⊗	
Head Room	4'-10'			X	X					X
	Over 10'	⊗	⊗	⊗		⊗	⊗	⊗	⊗	⊗
		9	7	6	5	8	10	6	8	6

NOTE: na = not applicable.

Figure 24. Example of a Dispatching/Accumulating Activity Analysis - Material Handling Equipment versus Operation and Move Factors.

The results of the analysis reveal that systems employing the following types of equipment should be investigated further:

Ident. & Sorting activity - mechanized equipment.

Storage method - shelf, fixed rack, flow rack.

Order Picking activity - crane, hoist or stacker crane.

Dispat./Accum. activity - crane, hoist or stacker crane.

Several alternative solutions should be developed based on the above types of equipment, and their technical and economical feasibility should be carefully evaluated. Consideration should be given also to the compatibility of the equipment used in one area or activity of the warehouse with the equipment used in the other activities. For instance, in the example used, a stacker crane would be appropriate for storing items on a fixed rack, retrieving (picking) them from storage and also taking them to the packing area or the shipping area. The advantages gained with the method proposed here is that it directs the analyst to the investigation of only the most profitable types of equipment. Valuable time can be saved if the proposed procedure is followed.

The final decision should be made on the basis of a comparison of tangible and intangible economic factors. As an example, an economic analysis will be conducted using the rate of return method. Assume that the analysis of the feasible solutions has shown three promising alternatives with the expected investments, annual receipts and annual expenses for the following five years as presented in the table below.

The straight-line method was used to calculate depreciation over a five years period. It is assumed that the company is in the 48 per cent tax bracket. The rates of return (using compound interest) are calculated as follows:

	SYSTEM		
	A	B	C
1. Total Investment	200,000	250,000	310,000
2. Annual Receipts	80,000	95,000	110,000
3. Annual expenses			
Depreciation	40,000	50,000	62,000
Other Costs	20,000	30,000	35,000
Total	60,000	80,000	97,000
4. Net Profit (2-3)	20,000	15,000	13,000
5. Income Taxes (48%)	9,600	7,200	6,240
6. Net profit After Taxes (4-5)	10,400	7,800	6,760
7. Recovery of Investment (5 years)	40,000	50,000	62,000
8. Return on Investment (6+7)	50,400	57,800	68,760
9. Rate of Return, i^*	8%	5%	4%

*Calculated as follows: $\dfrac{\text{total investment}}{\text{return on invest.}} = \dfrac{(1+i)^5 - 1}{i(1+i)^5}$

The last step in the analysis will be an evaluation of the intangible benefits of each alternative solution. A method developed by Apple (1) will be used as an example of the type of calculation required.

All of the intangible benefits derived from each of the alternative solutions should be listed and weighted according to an estimate of their relative importance. Each benefit is then evaluated for each alternative in terms of its effect on the problem, and given a rating on the basis of 100 for the most important. A weighted rating is determined for each alternative solution by multiplying the importance value of each benefit by the benefit rating.

Assume that the intangible benefits applicable to the three hypothetical solutions discussed earlier, A, B, and C, are those listed in Figure 25. After assigning importance values and ratings, and performing the necessary calculations, it appears that solution B is the most advantageous from this point-of-view.

Since solution A was found to be the best solution from the viewpoing of economics, the analyst is now forced to assign some dollar value to the calculated weighted ratings to determine the effect of the intangible benefits on the three alternative solutions. This dollar quantification of the ratings is a very difficult process. Experience and good judgment play an important part in developing the best way of doing this. Each analyst, then, should develop his own method.

When the tangible and intangible economic analyses have been completed and combined, the results should be presented to management for approval. If the expected rate of return is not sufficient to justify the investment, the project should be discontinued.

Intangible Benefits	Importance Value	Adjusted Importance Value	ALTERNATIVE SOLUTIONS					
			A		B		C	
			Rating %	Wgt'd Rating	Rating %	Wgt'd Rating	Rating %	Wgt'd Rating
1. Better customer service	100	17	90	15.3	70	11.9	80	13.6
2. Less damage, pilferage	95	16	75	12.0	85	13.6	60	9.6
3. Better control of inventory	85	15	60	9.0	90	13.5	90	13.5
4. More positive control of operators	75	13	80	10.4	100	13.0	80	10.4
5. Less space requirements	60	10	50	5.0	60	6.0	75	7.5
6. Reliability of equipment	55	9	80	7.2	90	8.1	60	5.4
7. Flexibility	45	8	75	6.0	80	6.4	75	6.0
8. Safety	30	5	75	3.8	80	4.0	70	3.5
9. By-product aut. accounting	25	4	90	3.6	70	2.8	70	2.8
10. Public relations value	20	3	75	2.2	85		85	2.7
Totals	590	100	-	74.5	-	81.5	-	75.0

Figure 25. Analysis of Intangible Benefits.

Conclusions

The procedure just described is intended only as a guide, and not as a substitute for good judgment on the part of warehouse designers. Only general rules were given, since every problem that a designer may encounter could not possibly be covered here. However, the application of the systematic approach proposed here will be helpful in reaching an optimum solution in a quicker and more efficient manner.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Many materials handling systems can benefit from mechanization and automation. The practice of applying mechanized and automated equipment in the warehousing function of an enterprise appears to be well justified as a means of improving the economics of operation of this important function.

Dollar savings from the application of automation in the warehouse are likely to appear in the following areas:

1. Reduced labor costs,
2. Reduced investment in inventory,
3. Reduced storage space,
4. Reduced losses of goods, because of reduced damage and spoilage.

However, direct dollar savings are not the only means of justifying automated handling systems. Many of the benefits of automation can not easily be assigned dollar values, but they may be equally or even more important to the success of the enterprise. Most important among these are:

1. Better customer service,
2. Better inventory control
3. Public relations value , and
4. Opportunities to integrate materials handling operations with data processing operations.

The feasibility of automating a warehouse activity appears to depend on a number of factors that pertain to the product being handled as well as to the operating characteristics of each particular company. Numerous factors have been identified in this study, but there are three that seem essential: presence of a large volume, relatively steady volume, and minimum variety in the size and shapes of the unit handled.

The feasibility of an automated warehouse can be established with the help of the procedure developed here. The procedure is intended only as a systematic approach to guide the engineer through the several phases of warehousing systems design.

The relative simplicity of the charts developed in this study might lead some readers to believe that the decision to automate a warehouse is a simple matter. On the contrary, the analysis of each particular installation is a very complex task and should be carefully conducted utilizing a systems approach.

It should be pointed out that the charts developed in this thesis are conceptual only and do not pretend to be technically accurate due to the lack of an adequate practical background on the part of the writer.

The charts are intended as aids to the engineer, to help him narrow the choice of equipment and techniques that could be applied to each warehouse activity. The approach proposed here will aid in solving the warehouse design problem, but it will not solve it. Securing an optimum solution still depends on the engineer's experience, knowledge and good judgment.

While conducting research for this thesis, several problem areas were recognized to be worthy of further investigation. They are presented here as an incentive to future work in this field.

1. Develop criteria for setting objectives in warehouse design

and methods of measuring the effectiveness of alternative solutions based on these objectives.

2. Develop and validate measures of effectiveness for use in designing and evaluating warehouse handling systems.
3. Develop a relative efficiency rating for various materials handling equipment and methods.
4. Expand on the relationships between the levels of mechanization and factors in analyzing an automated warehouse.
5. Develop a valid method of assigning dollar values to the intangible benefits.

APPENDIX

RESULTS OF SURVEY

I. GENERAL

1. What activities have been automated in your warehouse?

    a. Dispatching to Storage - 63%
    b. Order Picking - 58%
    c. Order Accumulation - 58%
    d. Record Keeping - 58%
    e. Storage - 46%
    f. Identification and Sorting - 29%
    g. Packing - 29%
    h. Receiving - 25%
    i. Loading - 21%
    j. Shipping - 21%

2. Is this a new installation?

    Yes - 96%　　No (modification of old) - 4%

3. Have any of your direct competitors automated their warehouses?

    Before - 13%　　After - 50%　　No - 17%　　Don't Know - 21%

4. Problems with unions.

    None - 100%

5. Do you have a centralized warehousing function? (one warehouse only)

    Yes - 46%　　No - 54%

6. Have any other sections, departments, processes or operations of your company been automated?

    Yes - 79%　　No - 21%

7. What has been the impact of the installation on public relations?

    Excellent - 50%　　Good - 38%　　None - 12%

Note: The percentage figures given do not necessarily add up to 100% due to the manner the answers were tabulated and to the nature of some of the questions.

8. Would you say that you have improved customer service measurably since the installation?

   Yes - 100%

9. Do you expect a change in the location of your warehouse five years from now?

   Yes - 8% No - 92%

10. How is your automated system operated?

    Manually - 54% Automatic - 54% Computerized - 29%

11. For what functions do you use computer control?

    a. Inventory control - 83%
    b. Billing - 75%
    c. Creation of order picking tickets - 75%
    d. Production control - 63%
    e. Order processing - 58%
    f. Accounting - 12%
    g. Materials handling - 8%

12. Not tabulated

13. What, if any, were your "start up" problems?

    a. Training problems - 83%
    b. Mechanical difficulties - 79%
    c. Electrical or electronic difficulties - 46%
    d. Operating personnel difficulties - 33%
    e. Vendor problems - 17%
    f. Customer problems - 8%
    g. None - 8%

14. Major benefits obtained from the automated warehouse.

    a. Better customer service - 92%
    b. Lower labor unit costs - 88%
    c. Less damage, pilferage - 79%
    d. Better inventory control - 67%
    e. More positive control of operators - 58%
    f. Less space and inventory requirements - 54%
    g. Public relations value - 38%
    h. By-product automatic accounting procedures - 21%
    i. Faster processing - 8%
    j. Safety - 4%

15. Would you install and operate another automated warehouse in your company?

    Yes - 100%

II. PRODUCT

16. What are the shapes of cases and goods handled?

    Regular - 87%   Irregular - 13%

17. What are the sizes of cases and goods handled?

    Less than one cubic foot - 33%
    One to five cubic feet - 46%
    More than five cubic feet - 21%

18. What is the largest length handled?

    Less than two feet - 17%
    Two to five feet - 71%
    More than five feet - 12%

    The largest width?

    Less than two feet - 38%
    Two to five feet - 58%
    More than five feet - 4%

    The largest height?

    Less than two feet - 40%
    Two to five feet - 50%
    More than five feet - 10%

19. What is the smallest length handled?

    Less than six inches - 21%
    Six to twenty four inches - 58%
    More than twenty four inches - 8%

    The smallest width?

    Less than six inches - 33%
    Six to twenty four inches - 46%
    More than twenty four inches - 4%

    The smallest height?

    Less than six inches - 71%
    Six to twenty four inches - 13%
    More than twenty four inches - 4%

20. What are the largest weights of cases and goods handled?

    Less than 100 lbs - 58%
    100 to 1000 lbs - 17%
    More than 1000 lbs - 25%

    The smallest weights?

    Less than one lb - 25%
    One to 50 lbs - 58%
    More than 50 lbs - 15%

21. What are the average weights of cases and goods handled?

    Less than 15 lbs - 27%
    16 to 30 lbs - 27%
    31 to 50 lbs - 20%
    More than 50 lbs - 27%

22. Customers demanding special handling.

    Less than one third of the customers - 63%
    More than one third of the customers - 12%
    None - 25%

23. What fraction of your products is fragile?

    Less than one fourth - 54%
    One fourth to three fourths - 12%
    More than three fourths - 29%

24. What fraction of your products is seasonal?

    Less than one fourth - 63%
    One fourth to three fourths - 21%
    More than three fourths - 13%

25. How much has product pilferage been reduced?

    To less than one half of what it was - 17%
    To more than one half of what it was - 13%
    Don't know - 54%

26. How much has product damage been reduced?

    To less than one half of what it was - 54%
    To more than one-half of what it was - 21%
    Don't know - 17%

III. OPERATION

27. How many different customers do you serve?

Less than 100 - 8%
100 to 2000 - 17%
More than 2000 - 54%

28. What is the number of line items stored?

Less than 1000 - 21%
1000 to 3000 - 17%
More than 3000 - 46%

29. What is the present volume in cases handled per day?

Less than 4000 - 50%
4000 to 10,000 - 17%
10,000 to 15,000 - 4%
More than 15,000 - 17%

30. Not tabulated

31. How many customer orders are handled per day?

Less than 100 - 21%
100 to 1000 - 42%
More than 1000 - 21%

32. In general, are orders composed of a number of different products?

No - 4%   Few - 17%   Many - 75%

33. How many different line items are handled per day?

Less than 400 - 38%
400 to 1200 - 13%
More than 1200 - 25%

34. How many line items in an average order?

Less than ten - 38%
11 to 40 - 38%
More than 40 - 13%

35. What fraction of total item shipped is automated?

Less than three fourths - 25%
More than three fourths - 75%

36. What is the peak volume per hour, in cases handled?

Less than 200 - 25%
200 to 800 - 25%
More than 800 - 50%

37. How does current delivery time compare to "before automation"?

No change - 8% Better now - 79%

38. Number of order pickers utilized now?

Less than five - 4%
Six to nine - 21%
Ten to twenty - 33%
Twenty to thirty - 17%
More than thirty - 17%

39. Number of order pickers utilized before automating?

Less than five - 41%
Six to nine - 13%
Ten to twenty - 33%
Twenty to thirty - 0%
More than thirty - 4%

40. Do you feel you have better control of the operators now?

Yes - 100%

IV. ECONOMICS

41. Have maintenance costs increased?

Yes - 63% No - 37%

42. More than expected?

Yes - 17% No - 50%

43. Did you achieve the savings you anticipated?

Yes - 71% No - 8% Partially - 8%

44. What was the anticipated pay-off time?

Two years - 21%
Three years - 17%
Five years - 29%
Other - 33%

45. Has the installation paid for itself in the specified pay-off period?

Yes 63% Not yet - 37%

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